Establishing a Business Case for CO$_2$-EOR with Storage

Prepared for:
Wyoming Oil and Gas Fair

Presented by:
Michael Godec, Vice President
Advanced Resources International, Inc.
Arlington, Virginia  USA

September 12-13, 2018
Caspar, Wyoming
Presentation Outline

- Overview of CO₂ Enhanced Oil Recovery
- CO₂-EOR – U.S. Status and Size of the Prize
- Making Carbon Management Economically Viable – Review of Incentives and Regulation
- Barriers and Opportunities
CO₂-EOR Process

While relatively simple in concept, successful application of CO₂-EOR entails sophisticated design, process/flow modeling, and continuous monitoring.

The injected CO₂ contacts and becomes miscible with the oil remaining in the formation, promoting its recovery.

In Gulf Coast oil fields, CO₂-EOR can produce as much oil as primary or secondary recovery.
CO₂ pipelines, linking natural & industrial sources of CO₂ with geologically favorable West Texas oil fields, established the U.S. CO₂-EOR industry.

CO₂-EOR Projects Linked to CO₂ and Pipeline Sources (2014)

- ~ 136 CO₂-EOR projects produce 300,000 barrels/day.
- Over 3.5 Bcfd (68 MM/year) of CO₂ is being injected (and stored) with 20% from industrial sources.
- The recently passed 45Q tax credits for CCUS are stimulating new activity.

Source: Advanced Resources International based on Oil & Gas Journal and other industry data, 2014.
Oxy Permian's CO₂-EOR Performance and History

Oxy produces 145,000 BOE/D from applying CO₂-EOR in the Permian Basin, investing $195 MM in conventional CO₂ floods and $50 MM in TZ/ROZ floods.

“We’re currently recovering hydrocarbons from the Grayburg down to the Devonian and realizing recovery factors above 60% in some of our CO₂ floods,” said Jody Elliott, president at Oxy’s Oil & Gas Domestic.

“At the end of 2015, Oxy began Phase 1 of a CO₂ flood at the South Hobbs Unit in New Mexico. The CO₂ flood is showing response, with production more than tripling since going online.”
In the U.S., primary recovery and water flooding have recovered about a third of the 624 billion barrel oil endowment, leaving behind 414 billion barrels. Much of this “left behind oil”, equal to 284 billion barrels, is technically favorable for CO$_2$-EOR and is widely distributed across the U.S.

Original Oil In-Place: 624 B Barrels
Remaining Oil In-Place: 414 B Barrels

Target for EOR
414 Billion Barrels

Proved Reserves
20 Billion Barrels

Cumulative Production
190 Billion Barrels

Source: Advanced Resources International, 2015.

Conventional Domestic Oil Resources
Favorable for CO$_2$-EOR

Source: Advanced Resources International internal analysis, 2016
"Next Generation" CO$_2$-EOR technology, applied to conventional oil fields offers a demand (and storage) of 37 billion metric tons of CO$_2$. Only a small portion of this CO$_2$ demand can be met by existing natural sources of CO$_2$.

<table>
<thead>
<tr>
<th>Basin/Area</th>
<th>Oil In-Place Favorable for CO$_2$-EOR</th>
<th>Recoverable with &quot;Next Generation&quot; Technology*</th>
<th>Economic Demand for CO$_2$ with &quot;Next Generation&quot; Technology**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Billion Barrels)</td>
<td>(Billion Barrels)</td>
<td>(Billion Metric Tons)</td>
</tr>
<tr>
<td>Lower-48 Onshore</td>
<td>232</td>
<td>60</td>
<td>27</td>
</tr>
<tr>
<td>Alaska</td>
<td>23</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Offshore GOM</td>
<td>29</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>**Total</td>
<td>284</td>
<td>80</td>
<td>37</td>
</tr>
</tbody>
</table>

*At an oil price of $75/B, a CO$_2$ price of $30 per metric ton and ROR (before tax) of 20%.
**Assuming 0.45 mt of CO$_2$ per barrel of recovered oil.
## CO₂-EOR/CO₂ Storage Potential in WY

<table>
<thead>
<tr>
<th></th>
<th>No. of Fields</th>
<th>Incremental Oil Production from CO₂-EOR (MM Bbl)</th>
<th>Purchased CO₂ Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technically Recoverable</td>
<td>89</td>
<td>2,101</td>
<td>18,434</td>
</tr>
<tr>
<td>Economically Recoverable</td>
<td>50</td>
<td>1,602</td>
<td>14,197</td>
</tr>
</tbody>
</table>

**Assumptions:**
"Next Generation" CO₂ EOR (1.5 HCPV CO₂, plus targeting poorly swept portions of the reservoir).
At an oil price of $60/B, a delivered CO₂ price of $25 per metric ton, and ROR (before tax) of 20%.
Distribution of Benefits of CO₂-EOR

<table>
<thead>
<tr>
<th>Notes</th>
<th>CO₂-EOR Industry</th>
<th>Mineral Owners</th>
<th>Federal/State Treasuries</th>
<th>Power Plant/Other Capturers of CO₂</th>
<th>General Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NYMEX Oil Price</td>
<td>$80.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Transportation/Quality Differential</td>
<td>($3.00)</td>
<td>($3.00)</td>
<td></td>
<td>$3.00</td>
</tr>
<tr>
<td></td>
<td>Realized Oil Price</td>
<td>$77.00</td>
<td>($3.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Less: Royalties</td>
<td>($13.10)</td>
<td>$10.90</td>
<td>$2.20</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Production Taxes</td>
<td>($3.20)</td>
<td>($0.50)</td>
<td>$3.70</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CO₂ Purchase Costs</td>
<td>($13.50)</td>
<td>($13.50)</td>
<td>$13.50</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>CO₂ Recycle Costs</td>
<td>($5.00)</td>
<td></td>
<td></td>
<td>$5.00</td>
</tr>
<tr>
<td>7</td>
<td>O&amp;M/G&amp;A Costs</td>
<td>($15.00)</td>
<td></td>
<td></td>
<td>$15.00</td>
</tr>
<tr>
<td>8</td>
<td>CAPEX</td>
<td>($7.00)</td>
<td></td>
<td></td>
<td>$7.00</td>
</tr>
<tr>
<td></td>
<td>Total Costs</td>
<td>($56.80)</td>
<td>$10.40</td>
<td>$5.90</td>
<td>$13.50</td>
</tr>
<tr>
<td>9</td>
<td>Income Taxes</td>
<td>($7.10)</td>
<td>($3.60)</td>
<td>$10.70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Net Cash Margin</td>
<td>$20.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Net Income ($/B)</td>
<td>$13.10</td>
<td>$6.80</td>
<td>$16.60</td>
<td>$13.50</td>
</tr>
</tbody>
</table>

CO₂-EOR provides a wide distribution of benefits:

- Federal and state treasuries receive $16.60/Bbl, equal to $37/mt.
- The power industry receives $13.50/Bbl, equal to $30/mt.
- The U.S. economy receives $30/Bbl, supporting well paying jobs and manufacturing.

1 Assumes an oil price of $80 per barrel (WTI) based on EIA AEO 2017 oil price for year 2022.
2 Assumes $3 per barrel for transportation.
3 Royalties are 17%; 1 of 6 barrels produced are from Federal and state lands.
4 Production and ad valorem taxes of 5% from FRS data.
5 CO₂ sales price of $30/metric ton including transport; 0.45 metric tons of purchased CO₂ per barrel of oil.
6 CO₂ recycle cost of $10/metric ton; 0.5 metric tons of recycled CO₂ per barrel of oil.
7 O&M/G&A costs from ARI CO₂-EOR cost models.
8 CAPEX from ARI CO₂-EOR cost models.
9 Combined Federal and state income taxes of 35%, from FRS data.
Source: Advanced Resources International internal study, 2017.
PetraNova: “Poster Child” of Carbon Utilization

PetraNova has installed post combustion CO₂ capture on a 240 MW coal-fired unit at the WA Parish power plant near Houston, Texas.

The 80 MMcf/d of captured CO₂ is transported and used for EOR at Hilcorp’s West Ranch oil field with an oil production goal of 15,000 B/D.

Source: NRG, 2017
Making Carbon Management Economically Viable

Our analysis shows that sales of CO₂, incentives (tax credits), R&D investment and other support make carbon capture and utilization economically viable.

- $28.50 per metric ton ($1.50/Mcf of CO₂) from the sale of CO₂ to the EOR industry, assuming a long-term, oil price of $75/B (WTI).
- Up to $35 per metric ton of CO₂ as “revenue neutral” tax credits (incentives) from incremental domestic oil produced by CO₂-EOR*.
- Substantially increased domestic jobs and associated investments that would further boost the U.S. economy and its tax base.

The goals now are to reduce CO₂ capture costs and support the pursuit of “next generation” CO₂-EOR technologies.

*Assumes one barrel of incremental domestic oil production creates $15.60 of incremental Federal/state tax revenues while using (and storing) 0.45 metric tons of CO₂. Note: $15.60 per barrel/0.45 metric tons of CO₂ per barrel equals $35 per metric ton of CO₂.
Current Efforts to Incentivize CCS

- FUTURE Act
- California Low Carbon Fuel Standards (LCFS) and Permanence Protocol
  - Rule to reduce carbon intensity in transportation fuels.
  - CCS projects under the LCSF must meet Protocol
  - Ethanol production with CCS allowable mechanism
  - Stringency as proposed may limit industrial participation
- State Incentives
## FUTURE Act Enhancements to IRC Section 45Q

<table>
<thead>
<tr>
<th>Previous 45Q</th>
<th>FUTURE Act</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 million metric ton cap</td>
<td>Eliminates 75 million metric ton cap; applies to new facilities that “break ground” by EOY 2023.</td>
</tr>
<tr>
<td>Credit based on “captured qualified CO₂”</td>
<td>After enactment, credit based on captured “qualified carbon oxide” (CO₂ and other carbon oxides)</td>
</tr>
<tr>
<td>$20/metric ton for CO₂ stored and not used for EOR</td>
<td>$50/mt for geologic storage and $35/mt for EOR (each rate phases up over 10-year period from 2017 to 2026).</td>
</tr>
<tr>
<td>$10/metric ton for CO₂ stored and used for EOR</td>
<td>Existing qualified facilities would continue to receive the original inflation adjusted $20 and $10 credit rates.</td>
</tr>
<tr>
<td>Credit rate is indexed for inflation beginning in 2010.</td>
<td>Credit rates indexed for inflation beginning in 2027.</td>
</tr>
<tr>
<td>Available to facility with capture equipment capturing at least 500,000 metric tons CO₂/year.</td>
<td>Capture &gt; 500,000 metric tons CO₂/year for electric generating units; &gt; 100,000 metric tons CO₂/year for other.</td>
</tr>
<tr>
<td>Credit available until the 75-million-ton cap is reached.</td>
<td>Credit goes to the owner of the capture equipment.</td>
</tr>
<tr>
<td></td>
<td>Available to “direct air capture” and “beneficial use”</td>
</tr>
<tr>
<td></td>
<td>Credit available for 12 years from the date the carbon capture equipment is placed in service.</td>
</tr>
</tbody>
</table>
FUTURE Act – Other Provisions

Other provisions include:

- Changes the taxpayer that receives the tax credit from the owner of the industrial facility that emits the CO\textsubscript{2} to the owner of the capture equipment that captures the CO\textsubscript{2}

- Allows the taxpayer to transfer the credit to the entity that:
  - Disposes of the qualified CO\textsubscript{2}
  - Utilizes the qualified CO\textsubscript{2}
  - Uses the qualified CO\textsubscript{2} as a tertiary injectant (for EOR).

- EPA GHGRP Rule (Subpart RR) basis for “certifying” storage

- The “devil will be in the details” as implementation guidance is developed by IRS
Is the FUTURES Act Enough?

- Continued RD&D to reduce costs of CO₂ capture
- Continued RD&D of “next generation” CO₂-EOR; especially targeting “carbon negative oil”
- Restructured/reformed regulations that do not inhibit CCUS/ CO₂-EOR applications at commercial scale
- Further incentives beyond 45Q?
  - Tax-exempt private activity bonds
  - Master limited partnerships
  - Incentives for CO₂ pipelines/pipeline expansions/buildout
  - CCS included in Renewable Portfolio Standards
  - State incentives
- USE IT Act introduced:
  - Coordinate development of permitting guidance
  - Establish two regional task forces to address infrastructure challenges.
Support for CO\textsubscript{2} Pipeline Infrastructure

In February 2017, the State CO\textsubscript{2}-EOR Deployment Work Group, led by Governors Matt Mead of Wyoming and Steve Bullock of Montana, recommended to Congress and the President the development of five priority CO\textsubscript{2} trunk pipelines as part of the national infrastructure initiative.

Potential Regional CO\textsubscript{2} Pipeline Corridors

(Illustrative Purposes Only)

Economic Impact of Proposed $15 Billion CO\textsubscript{2} Pipeline Investment ($75 Billion of Investment & $30+ Billion/Year Activity)

Expanding CO₂ EOR beyond West Texas/New Mexico entailed the construction of new pipeline systems:

- **Gulf Coast Region.** A 750 mile (1,200 km) CO₂ pipeline system (including the recent 325 mile (540 km) Green Pipeline) links natural CO₂ (Jackson Dome) and industrial CO₂ (e.g., Air Products Hydrogen) with Gulf Coast oil fields.

- **Rocky Mountain Region.** The 800 mile (1,300 km) CO₂ pipeline system (including the new 232 mile (390 km) Greencore Pipeline) links industrial CO₂ (e.g., Lost Cabin gas processing plant) with Colorado, Wyoming and Montana oil fields. A 110 mile (180 km) extension into North Dakota is under construction.
U.S. Regulation of Storage with CO$_2$-EOR

- From 15 years’ worth of R&D, a significant foundation of experience regarding CO$_2$ storage has been established.

- In 2010, U.S. EPA promulgated Underground Injection Control (UIC) well (Class VI) requirements for geologic storage of CO$_2$.
  - All Class VI CO$_2$ storage wells permitted to date associated with R&D projects; rule originally not intended to apply to R&D projects.
  - Most of the CO$_2$ storage wells permitted to date and in operation are Class II wells associated with CO$_2$-EOR projects.

- EPA guidance confirms that CO$_2$-EOR can result in stored CO$_2$; conversion to Class VI is not required for assuring storage.

- Concerns that legal and regulatory obstacles exist to allow CO$_2$-EOR to be viable source for CO$_2$ emissions reduction.
Establishing a Business Case for CO₂-EOR with Storage

CCS-Related Source Categories for Subpart RR of the GHGRP

Subpart PP: CO₂ Supply

Subpart UU: CO₂ Received

Subpart RR: CO₂ Sequestered

CO₂ source

CO₂ received

Facility Fence line

CO₂ injected

CO₂ produced

CO₂ entrained in fluids

CO₂ surface leakage, if any

Key
M = Meter
EL&V = Equipment Leaks and Vented Emissions

Geologic Formation
Greenhouse Gas Reporting under Subpart RR

- **Storage certification under 45Q may be established by EPA Subpart RR reporting**
  - Operators are required to submit monitoring, reporting, and verification (MRV) plan
  - 4 MRV plans approved; two for CO$_2$-EOR, one for saline, one for acid gas disposal.

- **Most significant concerns include:**
  - Process for and timeliness of EPA approval of MRV plans
  - What constitutes “new” activity -- and thus a new MRV plan
  - Extent to which MRV plans are subject to litigation
  - Conflicts w/ state mineral property/resource conservation law.
“Next Generation” CO\textsubscript{2}-EOR and Carbon Negative Oil – Is it Possible?

- Most life-cycle analyses (LCA) of CO\textsubscript{2}-EOR-related emissions are based on historical operations
  - Where CO\textsubscript{2} use was minimized per incremental barrel because of the high costs for CO\textsubscript{2}
- Such LCAs often do not represent the emerging paradigm where CO\textsubscript{2} storage is a co-objective.
- Such LCAs often do not represent latest efficiencies in CO\textsubscript{2}-EOR operations.
- Such LCAs often do not represent current refining operations.
  - Increasing portion of crude now transformed into non-combustible products -- asphalt, lubricants, waxes, chemical feedstocks.
## Characterization of CO$_2$ Utilization for CO$_2$-EOR

- **Historical**: 0.15 to 0.22 tonnes/bbl
- **Current**: 0.30 to 0.40 tonnes/bbl
- **“Next Generation”**: 0.40 to 0.50 tonnes/bbl
- **“NG EOR w/ ROZ”**: 0.50 to 0.55 tonnes/bbl
- **NG EOR Plus Storage**: 0.60+ tonnes/bbl
- **CO$_2$ Emissions/bbl**: 0.38 to 0.40 tonnes/bbl
Steps to Achieving Lower Cost, Publicly-Acceptable CO₂ Supply for CO₂-EOR

- Sell more CO₂ to CO₂-EOR projects
  - Through better utilization and better economics with “next generation” CO₂-EOR technologies

- Reduce the costs of CO₂ capture!!!
  - Requires doing projects, which cannot happen today w/o CO₂-EOR

- Pursue economies of scale for CO₂ transport; building upon existing infrastructure to the extent possible

- Gain public acceptance
  - Requires rigorous site selection, monitoring, and public outreach
  - Without imposing regulatory requirements inhibit deployment
“Learning by Doing” for Energy Industries

* LNG capital cost measured in USD/t and capacity measured in bcm.
** Other sources indicate learning rates as low as 18% for solar PV

Source: Worldwatch Institute; IEA; BTM Consult; ABS; NREL; IIIE; ABI; Drewry 2007; UN Berkeley ERG; Navigant Consulting.
Potential Barriers to Lower Cost, Publicly Acceptable CO₂ Supplies for CO₂-EOR

- Limitations of today’s CO₂-EOR and CO₂ capture technology
- Increased operator knowledge, comfort with, and willingness to pursue CO₂-EOR
  - Reducing the uncertainty of CO₂-EOR economics
- Achieving both requires:
  - Financial incentives to promote CO₂ supplies for CO₂-EOR
  - Research on and demonstration of “next generation” CO₂-EOR technologies
- Willingness/ability of regulators to permit/encourage CO₂-EOR and associated CO₂ storage
Overcoming Barriers to Large Volume CO₂ Supplies for CO₂-EOR

Today’s Emphasis

Competitive Costs for CO₂ Capture

Demonstrated CO₂-EOR Economics

Proof of Safe and Reliable Storage

Appropriate Regulatory Framework

Market Acceptance

Future Challenges

FINISH
Affordable, Reliable CO₂ Supplies for EOR Market
Opportunities

- **CO₂-EOR offers large CO₂ storage capacity potential.**
  - CO₂-EOR in oil fields can utilize a major portion of the CO₂ captured from industrial facilities for the next 30 years.

- **CCS and CO₂-EOR need each other**
  - The revenues (or cost reduction) from sale of CO₂ to EOR helps CCS economics, while producing oil with a lower CO₂ “footprint.”
  - Large-scale implementation of CO₂-EOR is dependent on CO₂ supplies from industrial sources.

- **“Carbon negative” oil is possible with CO₂-EOR.**
  - The volume of CO₂ injected/stored during CO₂-EOR can be greater than that associated with the emissions from the oil produced.

- **Passage of recent 45Q legislation critical – but is it enough?**
Concluding Thoughts

Become discouraged can be easy given the challenges posed by linking captured CO₂ supplies to CO₂-EOR and CO₂ storage.

- The experience from North America shows that innovative thinking, advances in technology and supportive policies can overcome these challenges.

- New emphasis on evaluating large-scale, longer distance transportation systems, linking CO₂ sources with oil fields, would help overcome one of the major challenges.

- So would comprehensive strategies involving research, incentives and more visionary analytical studies addressing the integration of EOR and CO₂ storage.

Combination of incentives, rational regulation, advances in technology can possibly lead to a “new dawn” for establishing a business case for CO₂-EOR with storage.